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GROUPTHINK AND THE BLUNDER OF THE GAUGES

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Abstract

We review the issue of the fallacy of the gauge concept in electromagnetism and discuss the possible role of groupthink in the perpetuation of this erroneous concept throughout the physics literature. Brief elementary arguments are presented to demonstrate the fallacy. The extreme simplicity of the demonstrations is sufficient proof that the norms of the scientific method have been ignored in this matter. Groupthink offers a plausible explanation for the perpetuation of the gauge fallacy for the past century and a half.

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Introduction

Groupthink [1] among economists is frequently suggested as the root cause of the recent near-collapse of worldwide economies. It is the origin of the derision directed at anyone who criticized the conventional view that economic stability was well-established. Social psychologist, Irving Janis is usually credited with coining the term. He maintains that group pressure reduces critical thinking and reality testing. Consequently, alternatives are ignored and outsiders are dehumanized.

We show that groupthink can also thrive in the physics community and offer the case of the fallacious concept of the electromagnetic gauge as a prime example. The gauge concept is found in all the textbooks dealing with classical and/or quantum aspects of electromagnetism. A recent web search of the term “electromagnetic gauge” generated well over a million “hits”. Reference [2] provides a comprehensive exposition of the errors and inconsistencies related to the gauge concept in the literature on electromagnetism. Reference [3] discusses the “peculiarity” of the Coulomb gauge, including its unrealistic requirement that Coulomb fields propagate instantaneously. We conclude that a significant factor in the survival of these errors over the past century and a half is the failure to maintain distinction among variables. This has fostered an Alice in Wonderland treatment of the variables by authors : “ It means just what I choose it to mean-neither more nor less”.

Brief demonstrations of the gauge fallacy

The standard orthodoxy of the gauge concept has been repeated essentially verbatim from one electromagnetism textbook to another over the past century and a half. The Lorenz gauge is at the heart of this orthodoxy. As a reflection of the uncritical acceptance of this concept, all textbooks (until very recently) have attributed the concept to H.A. Lorentz rather than its rightful author, L. Lorenz [4]. For example, the first two editions of Jackson’s “Electrodynamics” [5] attributes the gauge to H.A. Lorentz; the error is corrected in the third edition. We suggest that insufficient critical attention is given to the gauge concept itself. Our objective here is to show how easily the fallacy of the electromagnetic gauge is revealed. Groupthink is the likely reason for the lack of critical scientific review of this issue.

The fallacy of the Coulomb gauge

The Lorenz gauge is central to electromagnetism; however, the Coulomb gauge is invoked in some instances when “convenient”. Consider the fields around a solenoid whose current is increasing linearly in time. There are no Coulomb fields ($E_C = 0$); there are only induced fields ($E_I > 0$). In this example, E_I is solenoidal so that

$$\nabla \cdot E_I = 0 \; . \tag{1}$$

This equation says there are no point sources for E_I . Fields induced by solenoids are solenoidal. Coulomb fields, by contrast, are not solenoidal since $\nabla \cdot E_C = \rho/\epsilon$. The distinction between field types must be maintained. They have different physical characteristics and different origins.

The next step in this elementary demonstration is to invoke the equation, $E_I = -\partial A/\partial t$ where A is the vector potential. Since E_I is solenoidal, its source, A, must be solenoidal, i.e., $\nabla \cdot A = 0$. (Strictly speaking, $\partial(\nabla\cdot A)/\partial t = 0$.) There is no alternative. The equation $\nabla\cdot A = 0$ is generally labeled the Coulomb gauge. Thus, the gauge concept fails here. It presupposes that one is free to choose any function of time and space for $\nabla\cdot A$ because $\nabla\cdot A$ is irrelevant, and its choice does not affect the physics of a given problem. Clearly, this cannot be true for a solenoid. An arbitrary function of time and space for $\nabla\cdot A$ would violate the requirement that $\nabla\cdot E_I = 0$. If $\nabla\cdot E_I \neq 0$, then point sources for induced electric fields would exist for solenoids, which is false.

Thus, the equation $\nabla\cdot E_I = 0$ is a law of physics. It seems to be an inconvenient law, however. We were unable to find it expressed in any textbook, or in a wide variety of on-line lecture notes. Perhaps its absence is not surprising given its direct conflict with the gauge concept.

This simple example is sufficient to show that the gauge concept is incompatible with the elementary laws of electromagnetism. Nevertheless, we provide a second, more general example that includes the above as a special case, in the following.

The fallacy of the Lorenz gauge

Recall from the standard formalism (or from reference [2]) that the Lorenz gauge is introduced during the derivation the vector potential expression for the wave equation. A portion of the derivation is repeated here to help illustrate the key error in the process. Substituting the expression, $B = \nabla\times A$ into Maxwell's differential equation expressions for Faraday's law and Ampere's circuital law gives

$$\nabla^2 A + \partial^2 \mathrm{A}/\partial \mathrm{t}^2/\mathrm{c}^2 - \nabla(\nabla\cdot A + (\partial\varphi_C/\partial t))/c^2 = -\mu J_T \tag{2}$$

If the term in parentheses were zero, then Eq. (2) would represent a wave equation for A that is homogeneous in free space with only the true current, J_T , as the source term. *The fundamental assumption of the Lorenz gauge is that $\nabla\cdot A$ is meaningless, so no connection can exist between A and the Coulomb potential, φ_C.* The Lorenz gauge nicely circumvents this obstacle by applying a transformation function ψ to both the vector potential, A, and the Coulomb potential, φ_C . The application of the transformation function ψ to A and φ_C results in new, transformed variables A' and $\varphi_C{}'$. The central point of the Lorenz gauge is that, although it is assumed that $\nabla\cdot A$ *is unknown and meaningless* for the "real world" variables, one can, in principle, imagine a function ψ for any A and φ_C so that the following condition (Lorenz) applies for the resulting "imagined" variables,

$$\nabla\cdot A' + (\partial\varphi_C{}'/\partial \mathrm{t})/\mathrm{c}^2 = 0. \tag{3}$$

This leads to the desired result,

$$\nabla^2 A' + \partial^2 A'/\partial \mathrm{t}^2/\mathrm{c}^2 = -\mu J_T \ . \tag{4}$$

An important part of the Lorenz transformation is the fact that the sum of the electric fields is invariant to the transformation function, so that, the total field, $E = E_C + E_I = E_C{}' + E_I{}'$.

Invoking the dynamic form of Gauss' law, $\nabla\cdot(E_C + E_I) = \nabla\cdot(E_C{}' + E_I{}') = \rho/\epsilon$, gives

$$\nabla^2\varphi_C{}' + \partial^2\varphi_C{}'/\partial \mathrm{t}^2/\mathrm{c}^2 = \rho/\epsilon\,. \tag{5}$$

These are the wave equations for the two imagined (primed) potentials. By taking the time derivative of Eq. (4) and the gradient of Eq. (5), one obtains the wave equation for E that is invariant to the Lorenz transformation function. So, even if the real world $\nabla \cdot A$ is some meaningless random function, one can always imagine a ψ that will yield the desired form of the wave equation for E. That completes our brief review of the Lorenz gauge procedure for obtaining the wave equation. Now we demonstrate of the fallacy it that contains.

Return for a moment to Eqs. (4) and (5). If one takes the divergence of Eq. (4) and the time derivative of Eq. (5) and applies the Lorenz condition, the following important result is obtained,

$$\nabla \cdot J_T + \partial\rho/\partial t = 0 \tag{6}$$

In other words, the Lorenz condition is essential to the continuity equation for the imagined variables. The crucial question we raise relates to the real world variables and the continuity condition for that case. The continuity condition must be consistent with all variables, including, especially, the unprimed, real world variables that can be computed or measured in a laboratory experiment. The only way for that to happen is if

$$\nabla \cdot A + (\partial\varphi_C/\partial t)/c^2 = 0, \tag{7}$$

in the unprimed, real world, Eq. (2) above.

This gives,

$$\nabla^2 A + \partial^2 \mathrm{A}/\partial \mathrm{t}^2/\mathrm{c}^2 \ = \ -\mu J_T \tag{8}$$

Substituting Eq. (7) into the dynamic Gauss' law gives,

$$\nabla^2 \varphi_C + \partial^2 \varphi_C/\partial \mathrm{t}^2/\mathrm{c}^2 = \rho/\epsilon \tag{9}$$

As with the unprimed variables, if one takes the divergence of Eq. (8) the time derivative of Eq. (9), and applies Eq. (7), then Eq. (6) results. Only in this way is the continuity condition consistent with the unprimed variables, as it must be if these variables are to represent the essential physics of the problem at hand.

Equation (7) has nothing to do with the Lorenz gauge. It applies to the unprimed variables, in direct contradiction to the basic assumption of the Lorenz gauge. Since it applies to these variables, it is, by definition, a law of physics. So, contrary to the fundamental assumption of the gauge concept, there is a fundamental connection between the dynamic Coulomb potential and the vector potential. It is a previously overlooked law of physics, rooted in the requirements of the continuity condition. Thus, the gauge concept is an unnecessary and erroneous complication.

A relevant observation here is that the new law of physics represented by Eq. (7) is completely consistent with the overlooked law (Eq. (1)) discussed in the first example. In the absence of Coulomb fields (as in the solenoid case), or for static or quasi-static Coulomb fields, Eq. (7) requires that $\nabla \cdot E_I = 0$.

Conclusions

The fallacy of the electromagnetic gauge concept is easily demonstrated from elementary considerations. Rousseaux [6] has independently arrived at similar conclusions using a variety of examples. The simplicity of the two separate proofs provided here (and those in reference [6]) indicates that groupthink has subverted the norms of the scientific method regarding the electromagnetic gauge. The pervasiveness of the gauge concept and its longevity in the physics literature warrant its nomination for the physics blunder of the ages.

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